

SEASONAL VERTICAL DISTRIBUTION OF THE SAHARAN AIR LAYER BASED ON 5 YEARS OF CALIPSO OBSERVATIONS

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ABSTRACT

The Saharan Air Layer (SAL) influences large scale environment from West Africa to eastern tropical America. The SAL is characterized by dry and hot air and transports large amounts of dust aerosols. Dust aerosols are known to have important impacts on earth's radiation budget and hydrological cycle, ocean biogeochemical cycles and atmosphere chemical composition. The vertical distribution of the SAL is not well established due to lack of systematic measurements away from the continents. However, this can be overcome by using the observations of the space lidar CALIOP on board CALIPSO. By taking advantage of CALIOP's capability to distinguish dust aerosols from other classes of aerosols through depolarization, the seasonal vertical distribution of the SAL is here analysed at 1 degree horizontal resolution over a period of 5 years. Results show the latitudinal displacement of the SAL between winter $[-5, 15]^{\circ}\text{N}$ and summer $[10, 30]^{\circ}\text{N}$. SAL during winter is found between the surface and 3 km near Africa, while its top level drops to 2 km near South America. In summer, SAL ranges from 1 to 5 km altitude near Africa, while above the Caribbean Sea its top drops to 4 km.

1. INTRODUCTION

It is well known that large quantities of Saharan dust are transported across the tropical Atlantic throughout the year as a result of large-scale Saharan dust outbreaks, with the maximum occurring during summer. These dust outbreaks are mostly confined to a deep mixed layer, commonly referred to as the Saharan Air Layer (SAL) (see Figure 1 for an example of SAL as seen from CALIPSO observations), which often reach North America (in summer) and South America (in winter) [2]. The SAL long range transport is enhanced by the persistent temperature inversions that exist at its base and top: daytime heating by dust tends to counter night time radiative cooling, thus keeping the SAL relatively warm and stable as it crosses Atlantic. Dust concentrations are several times higher within the SAL than in the marine boundary layer below.

Dust interacts with radiation through scattering and absorption in the visible and thermal infrared spectrum. In addition, dust may serve as cloud condensation nuclei (CCN) or ice nuclei (IN) thus affecting cloud microphysics. It also plays a crucial role in fertilizing large areas of the oceans by deposition of nutrients like iron. Furthermore, dust aerosols modify atmospheric composition through heterogeneous reactions on their surface.

Besides, dust affects the quality of retrieval from satellite observations (e.g. temperature). Historical data analysis show that there is a robust negative correlation between atmospheric dust loading and Atlantic SST, consistent with the notion that increased (decreased) Saharan dust is associated with cooling (warming) of the Atlantic during the early hurricane season (July to September) [3]. Recent studies have shown that the SAL can suppress tropical cyclogenesis and inhibit Atlantic hurricane formation.

The SAL has been studied with dedicated campaigns at both sides of the Atlantic, e.g. PRIDE, or using space observations due to lack of systematic measurements away from the continents. However the campaigns are restricted in time, while satellite observations of thermodynamic variables are affected by the presence of dust. Moreover, satellite measurements of aerosols, particularly in the visible, mostly provide column integrated properties like the optical depth, without information about the vertical distribution. On the other hand, new generation infrared sounders now bring reliable information on the dust layer mean altitude [5], but their new established results still need further validation. Overall, there is lack of information about the vertical distribution.

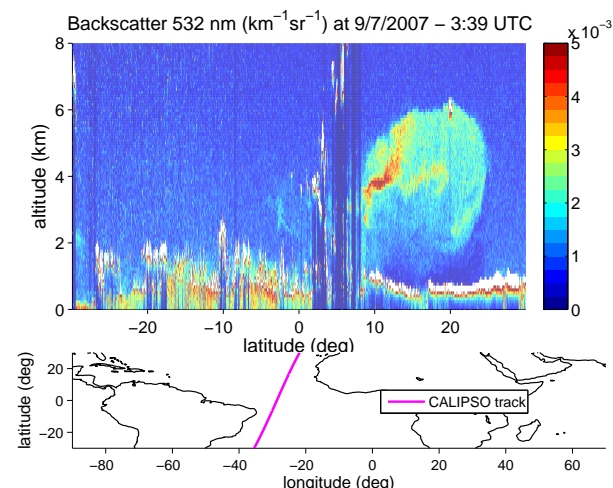


Figure 1: Example of the SAL at 9 July 2007. Top figure shows CALIOP attenuated backscatter coefficient at 532 nm. The SAL can be seen in the region $[8, 25]^{\circ}\text{N}$ between 1.5 and 6.5 km. White regions denote clouds. Bottom figure presents the CALIPSO track.

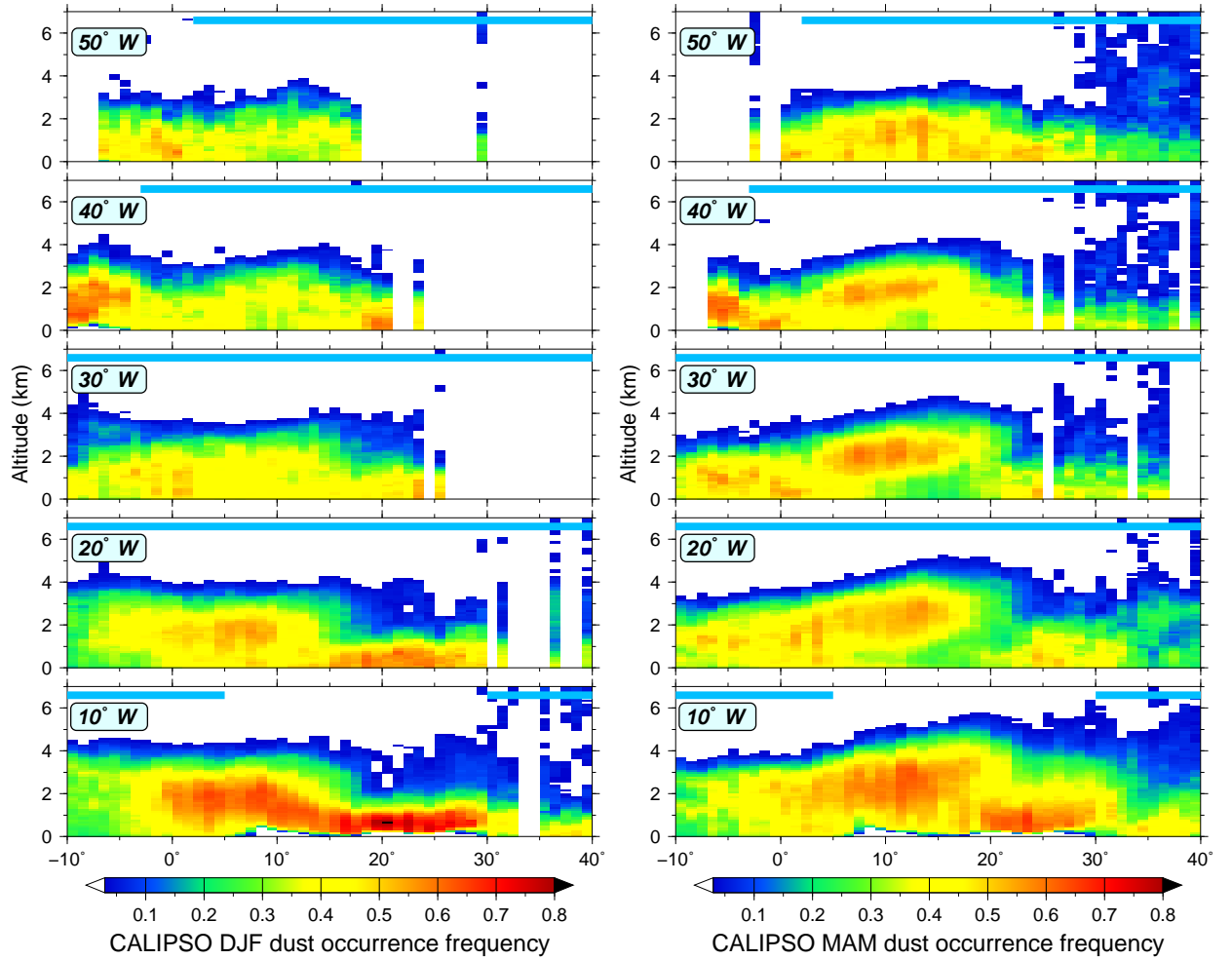


Figure 2: Vertical distribution of dust aerosols above the Atlantic Ocean at five longitudes (10° , 20° , 30° , 40° and 50° W) during the winter (DJF) and spring (MAM) seasons from 5 years of CALIPSO observations. The cyan line at the top of each cross section marks the ocean.

bution of the SAL in a climatological sense. The two-wavelength lidar CALIOP, launched on board CALIPSO in April 2006, permits an accurate determination of the aerosol vertical distribution, at global scale. Previous studies based on CALIPSO observations examined the vertical distribution of dust aerosols either with longitudinal or latitudinal means, bringing a zonal view of it [e.g. 1]. In this study, the seasonal vertical distribution of the SAL is presented based on 5 years of CALIPSO observations at 1 degree horizontal resolution.

2. CALIOP DATA

The CALIPSO satellite scope is to provide global profiling measurements of cloud and aerosol distribution and their properties. The primary instrument onboard CALIPSO is the first polarization lidar in space CALIOP, based on a Nd:YAG laser operating at 532 nm and 1064 nm, and measuring the degree of linear polarization of the return signal at 532 nm [6]. CALIPSO is part of the so-

called “A-Train” constellation of satellites, which are in a 705 km sun-synchronous polar orbit crossing the equator twice a day. The beam diameter of CALIOP is about 70 m at the Earth’s surface with a 16 day repeat cycle. CALIOP level 1b data (normalized attenuated backscatter) have horizontal and vertical resolution of 0.33 km and 30 m, respectively, up to 8.2 km altitude at 532 nm.

In this study, use is made of the level 2 data from CALIOP observations (version 3.01) above the Atlantic during the last 5 years (June 2006 – May 2011). There are three basic types of level 2 data products: layer products, profile products and the vertical feature mask, but only the 5 km aerosol layer product is used here. After identification of clouds and aerosols layers from the 532 nm attenuated backscatter profiles, follows the classification of these layers as clouds or aerosols, and finally the determination of the aerosol type [6]. Here, only aerosol layers with high confidence are used (Feature Type QA = 3). However, some misclassification may still occur in case

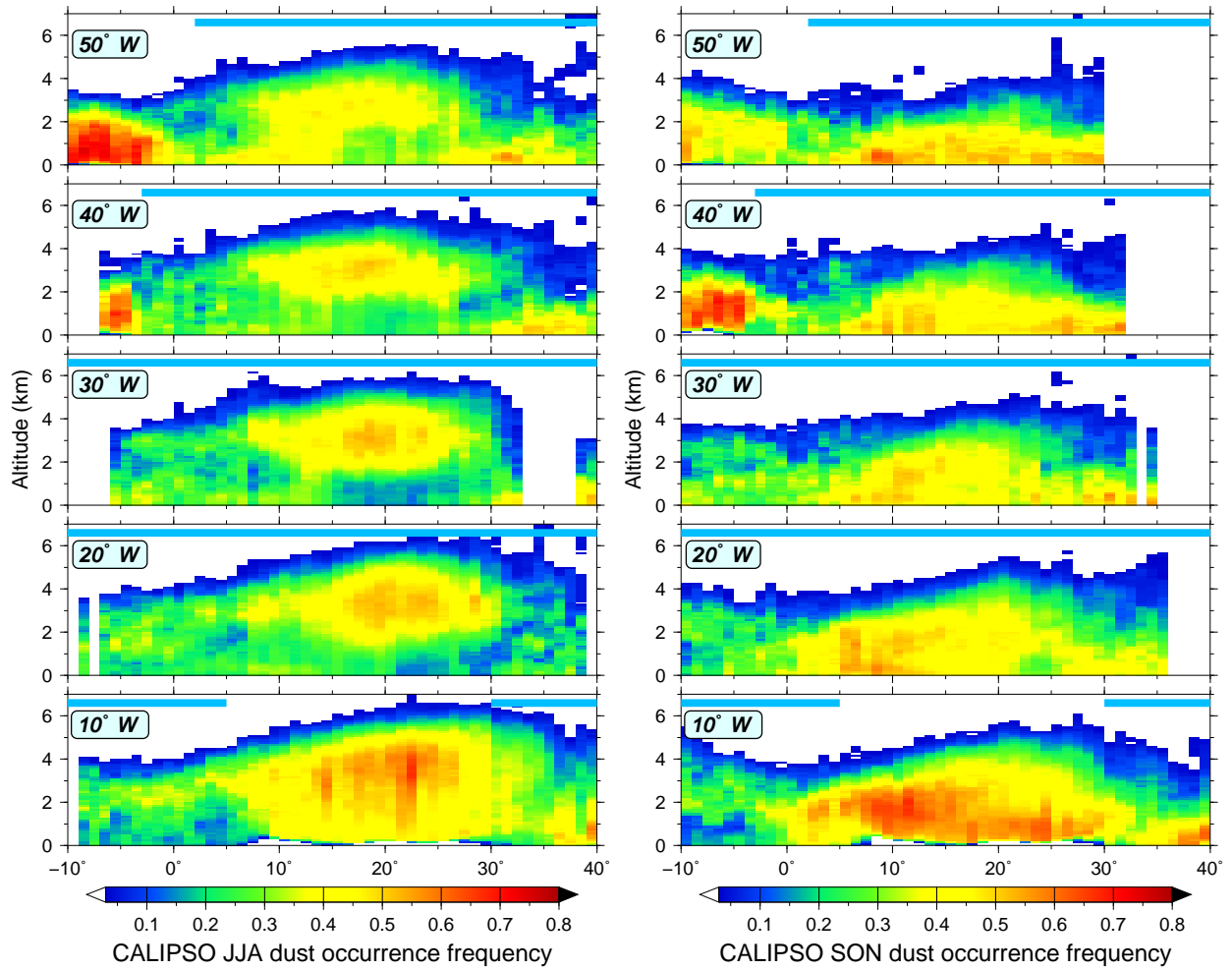


Figure 3: Same as Figure 2 but for summer (JJA) and fall (SON) seasons.

of dust aerosols, as they may be misclassified as clouds, mainly in three cases: i) very dense dust layers near their sources, ii) moderately dense dust layers transported to high latitudes, where cirrus clouds can be present even at low altitudes and iii) moderately dense dust layers transported vertically to high altitudes even at low latitudes, where usually cirrus are found. However, the analysis of [4] for July 2006 (version 2) showed that the misclassification of dust as cloud occurs for $< 1\%$ of the total tropospheric cloud and aerosol features found.

Thanks to depolarisation at 532 nm, CALIOP is able to discriminate between dust and other types of aerosols (smoke, continental, marine), which generally do not depolarize light as they are mainly spherical. Indeed, the depolarization ratio allows the discrimination between spherical and nonspherical particles, as the 180° backscatter signal from spherical particles retains the polarization of the incident beam, whereas backscatter from nonspherical or irregular particles is depolarized. The better identification of dust aerosols in comparison to other types from CALIOP has been confirmed with

AERONET measurements, with percentage of agreement 91%. In order to take into account the change of dust aerosols optical properties with transport, the class “polluted dust” is used in combination with the “dust” class. It is known that the polluted dust class may also contain smoke or polluted continental aerosols, but the results on the regions possibly contaminated by these aerosols are avoided or interpreted with caution.

It is known that the retrieval of backscatter and extinction coefficients from elastic lidars like CALIOP strongly depends on the lidar ratio. In this study, in order to avoid this dependence, which should have considerable impact on the statistical results, the dust occurrence frequency (ranging from 0 to 1) is reported instead of a more usual lidar parameter. Also, because of the detection of the layers (clouds or aerosols) at different horizontal resolutions (0.333, 1, 5, 20 and 80 km), and their report at the resolution of 5 km during their identification, layers detected at higher spatial resolutions seem to overwrite. In order to avoid counting several times the same layer, this overwriting has been corrected.

3. RESULTS AND DISCUSSIONS

Figures 2 and 3 present the seasonal vertical distribution of the SAL. Latitude (x-axis) – altitude (y-axis) occurrence frequency cross sections with 1 degree resolution are shown for 5 longitudes, from the west coast of North Africa (10°W, bottom) to the east coast of South America (50°W, top). The occurrence frequency value offers a qualitative description of the distribution of dust aerosols, with stronger values near sources and lower ones away from them due to dispersion and deposition of dust plumes. Therefore, the occurrence distribution may slightly change when passing from continent to ocean (indicated by the cyan line at 6.5 km), as the layers detection above ocean is more robust. An important feature is that dust aerosols do not overpass systematically the altitude level of 6.5 km, even in summer (occurrence percentage $\geq 3\%$ above it). There is an obvious seasonal cycle, with thin low altitude SAL during winter and thick more elevated SAL during summer.

During winter (Figure 2–left), SAL is found between [–5, 15]°N off West Africa, and between the surface and 3 km. By arriving to South America its top goes down to about 2 km. In the upper levels (2–4 km) above Africa biomass burning aerosols are also found, as shown, for example, by the AMMA and SAMUM-2 campaigns measurements. It is the dry season and biomass burning emissions from the Sahel and more southern regions inject smoke aerosols at this altitude levels. However, taking into account only the dust class of CALIPSO and not the combination dust and polluted dust, does not change significantly the results (not shown). This means that in the elevated layers there are indeed dust aerosols and not only a mix of dust and smoke. The export of dust aerosols northern than 15°N in the Atlantic Ocean, below 1.5 km, is not part of the SAL, as it will be demonstrated by its seasonal evolution.

During spring (Figure 2–right), SAL moves northwards. Off West Africa it occurs between [0, 20]°N in the altitude range 1–4 km, while its maximum altitude is reached at about 13°N. Towards South America (and south Caribbean this time) its top altitude drops to 2–2.5 km, while now the lowest levels are in contact with ocean. At longitudes 20°W and 30°W, the influence of the trade winds can now be observed at SAL northern lower side, which are giving its characteristic oval shape (see also Figure 1).

The oval shape of the SAL can be more clearly observed during the summer season (Figure 3–left). The SAL is observed more northward than in spring, [10, 30]°N, in the altitude range 1.5 to 5 km off West Africa. At the Caribbean Sea, (SAL does not reach South America during summer) it is found between [5, 25]°N, where the top altitude is at 4 km. However now, SAL presents two parts, the southern part (\sim [5, 15]°N) is in contact with ocean, while the northern part (\sim [15, 25]°N) has its lowest levels at about 1.5 km. Again, this seems to be a result of the influence of the trade winds. Also, from the occurrence

frequency can be seen that the maximum of the SAL, except for its descent, is shifted southward with transport, from 22°N above Africa to 18°N above Caribbean.

Finally, during fall (Figure 3–right), SAL turns southwards in comparison to summer, and lies between [0, 25]°N, from the surface up to 4 km off West Africa. Close to America, its top altitude drops to about 2 km 50°W.

These results, at 1 degree horizontal resolution, offer a better description of the SAL, not accessible up to now, at least vertically. In addition, ongoing work using wind fields from the ECMWF will examine their impact on the vertical distribution of dust. Moreover, these results could prove being helpful for testing model capabilities to reproduce the SAL vertical distribution on a seasonal scale or as input climatological data. Also, they can be used as a priori information to UV (like TOMS or OMI) or IR (like AIRS or IASI) satellite instruments, which are known to be sensitive to the vertical distribution of dust aerosols, in order to improve the quality of their geophysical retrievals.

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ACKNOWLEDGMENTS

We thank the ICARE Data and Services Center (<http://www.icare.univ-lille1.fr>) for providing us with CALIPSO data. This work has been supported in part by the European Community under the contract FP7/2007–2013 (MACC project).